Toward the Parameterization of Organized Convection in GCMs

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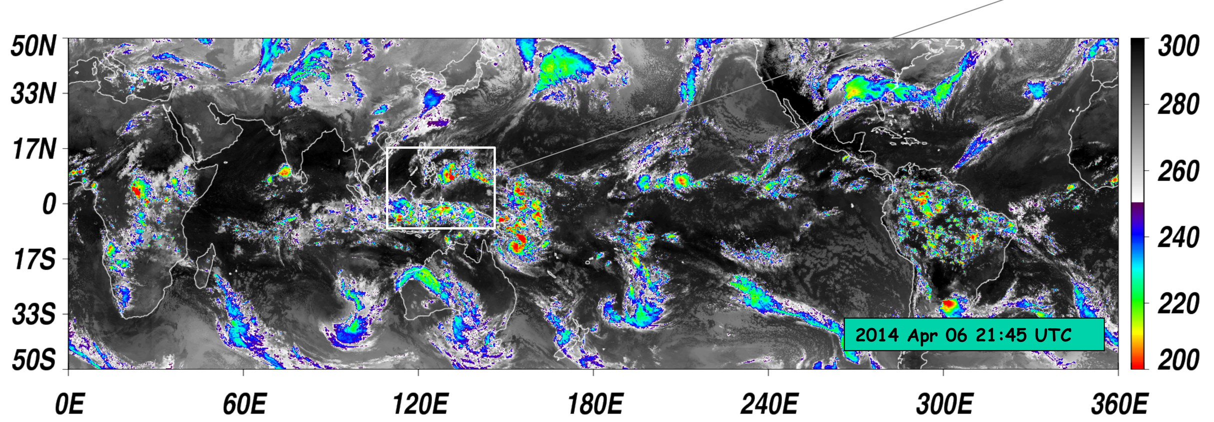
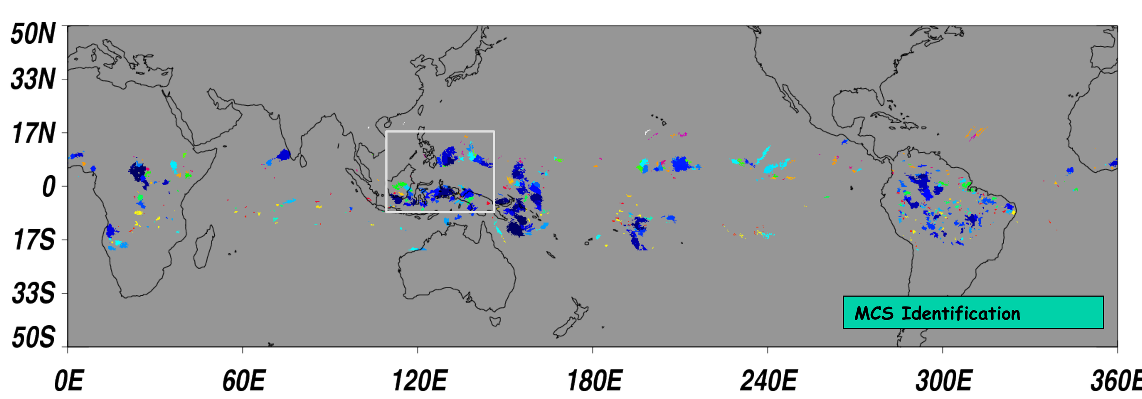
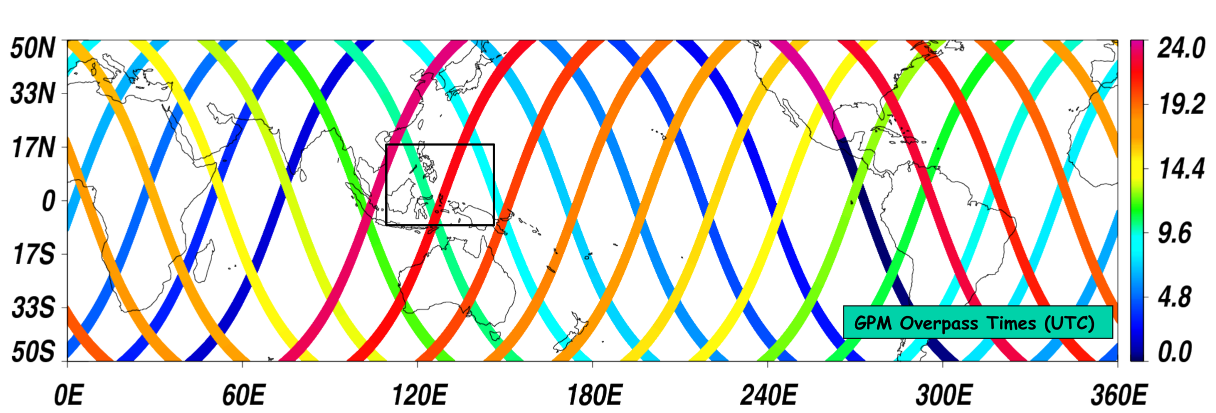
1. Introduction and Motivation

- Organized convection (e.g. mesoscale convective systems [MCSs]) is typically associated with heavy rainfall and thick anvil (ice) clouds. While occurring infrequently (~5% of the time), organized convection may contribute up to ~50% of Earth's rainfall.
- Organized convection is important for vertical momentum transports (relevant to MJO dynamics, for instance); associated anvils may be important for deep convective cloud feedbacks as well.
- Most global climate models (GCMs) do not simulate organized convection. Since many GCMs will remain at the ~50-200 km resolution for CMIP6, substantial effort must be devoted toward parameterizing organized convection (which is our goal for the GISS GCM).







- Using the CPC Globally Merged IR product (top panel above), we identify MCSs (center panel above; using the Fiolleau and Roca [2013] algorithm) and map GPM data products (e.g. Spectral Latent Heating [SLH] product, DPR rainfall, convective/stratiform flags) to MCS tracks. Example GPM orbits for 2014 April 06 are shown in the bottom panel; orbital swaths co-located (in time) with the MCSs identified at 21:45 UTC are outlined in the boxed regions of the above figure for visual reference.
- Organized convection is often associated with **diabatic heating profiles that peak at higher altitudes** (initially due to **convectively-detrained ice content** increasing by deposition in a moist environment). The Houze (1989) schematic below notes a few important organized convection processes (region where detrained ice occurs: boxed in red).
- In this poster, we discuss ways to delineate unorganized from organized convection using MCS-mapped GPM heating profiles. These profiles will serve as targets for parameterization development. Toward parameterizing organized convection, we then describe our new convective ice parameterization (*that can yield the detrained ice that feeds an anvil*).

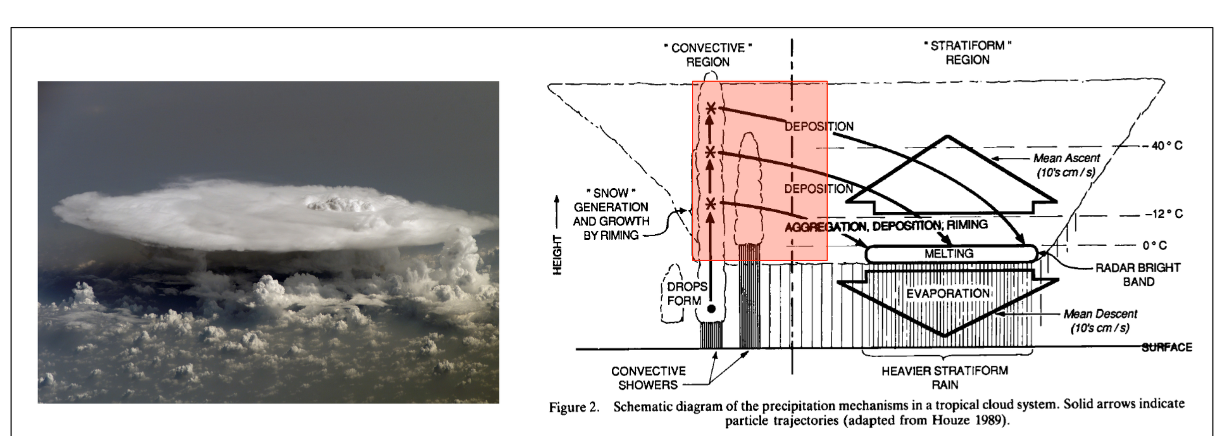
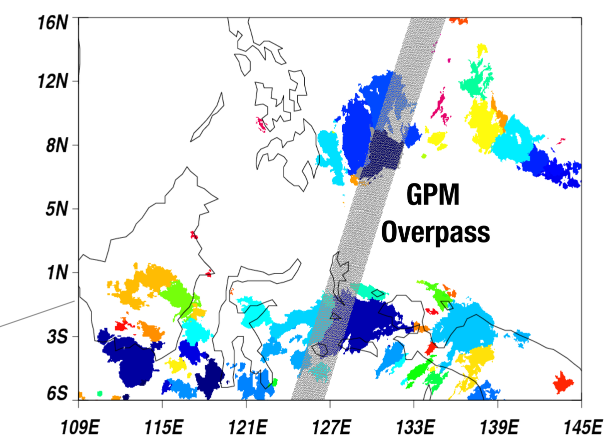


Figure 2. Schematic diagram of the precipitation mechanisms in a tropical cloud system. Solid arrows indicate particle trajectories (adapted from Houze 1989).

2. Delineating Organized from Unorganized Convection Using GPM



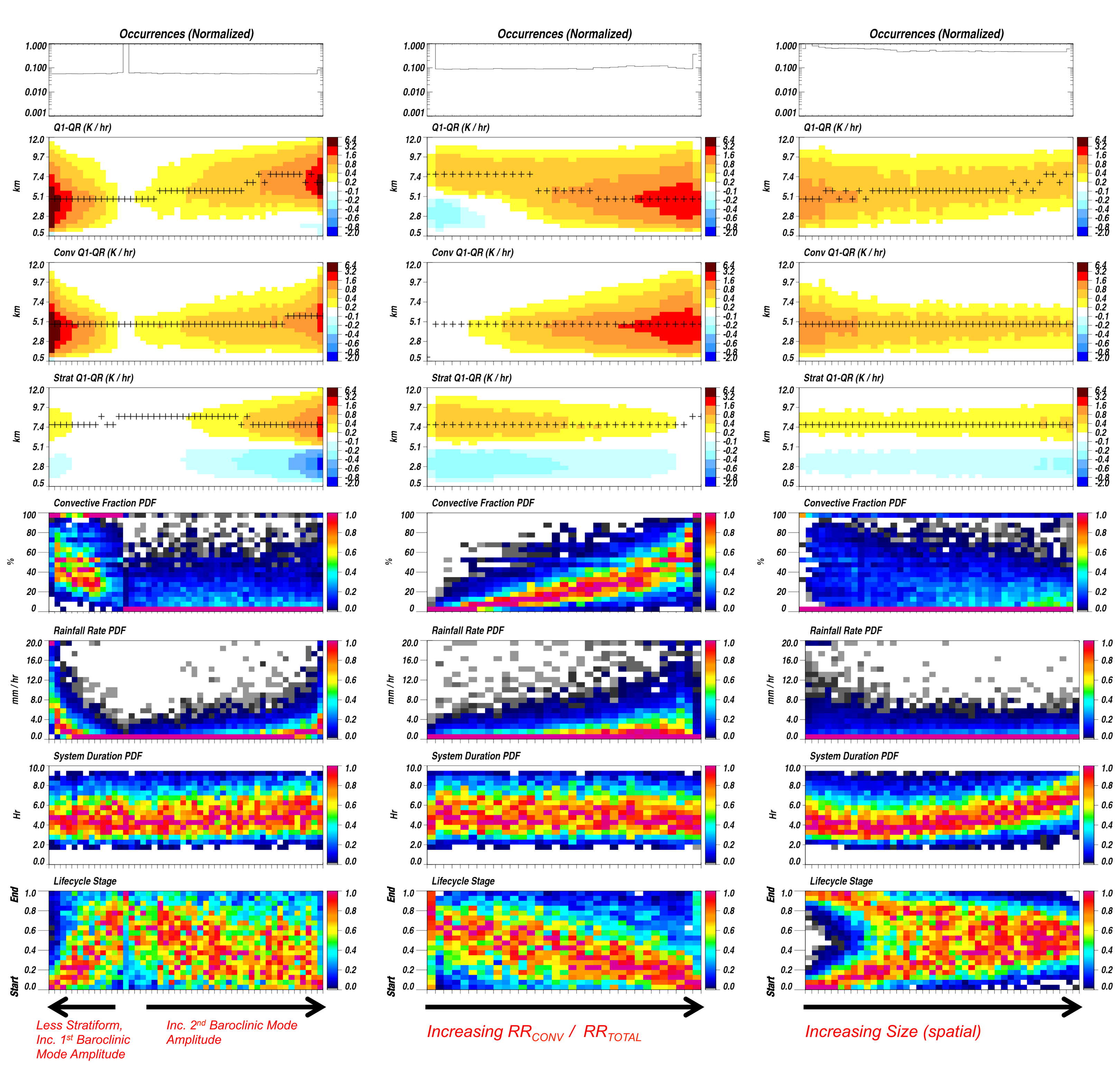
GPM samples systems of varying sizes (**see figure to left**), and at varying lifecycle stages. From March – December 2014, ~20K systems were observed. We analyze convective systems only if GPM system coverage exceeds 25% of the system spatial extent (as identified by IR). We also analyze system duration and lifecycle stage to determine to what extent organization is tied to duration or stage.

GCMs MUST MAKE (AND/OR SUSTAIN) THE RIGHT HEATING PROFILE AT THE RIGHT TIME, WHICH REQUIRES OBSERVATIONAL KNOWLEDGE OF SUCH DISTINCTIONS. WHAT IS THE BEST WAY TO SORT CONVECTIVE STATES? BELOW, WE SHOW THAT MORE THAN ONE SORTING APPROACH PROVIDES USEFUL INFORMATION ON CONVECTION.

① Left Column Below: Sorting by diabatic heating top-heaviness yields separation between large-amplitude 1^{st} / 2^{nd} baroclinic mode convection states. Strongest amplitude 1^{st} baroclinic (convective) and 2^{nd} baroclinic mode (stratiform) states are **both** found earlier in the MCS lifecycle; however, the strongest convective mode is rarely observed in later stages. ***Possible Interpretation: MCS may undergo oscillations in organization (affected by local environment changes as opposed to a systematic progression of organization with stage/duration); heating profile structure is only weakly constrained by convective fraction.***

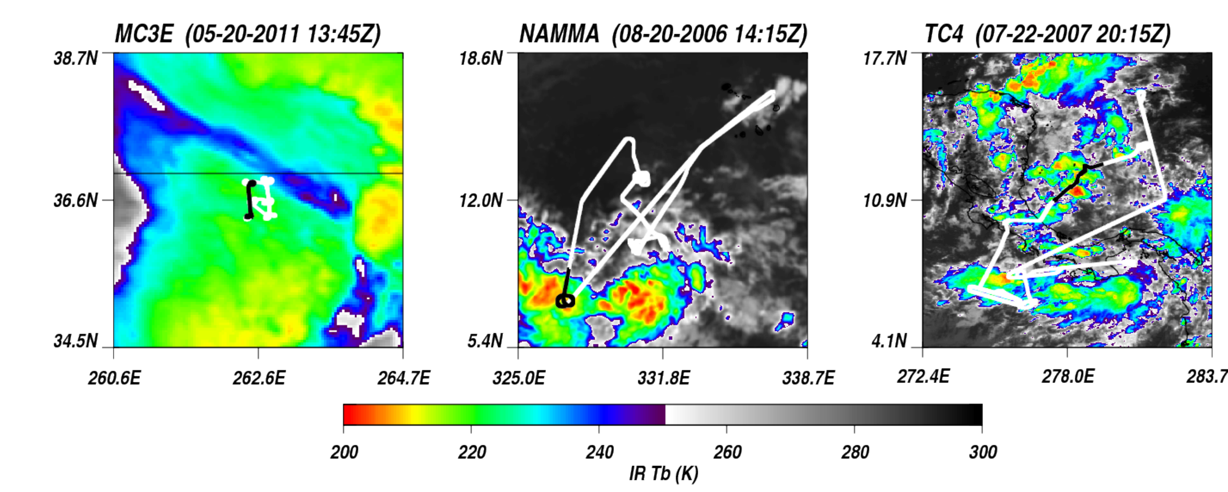
② Center Column: Sorting by convective rainfall fraction yields composite heating structures that broadly vary as a function of lifecycle stage (and thus, the two very different modes in Sorting 1 are averaged in varying fractions over the lifecycle). ***Key Points: Convective fraction exhibits greater variation with system stage. Consistent with Column 1, strong convective heating is found earlier, with composite-average stratiform heating weaker throughout (consistent with an average of all stratiform modes in Sorting 1; **note the non-linear color scales**).***

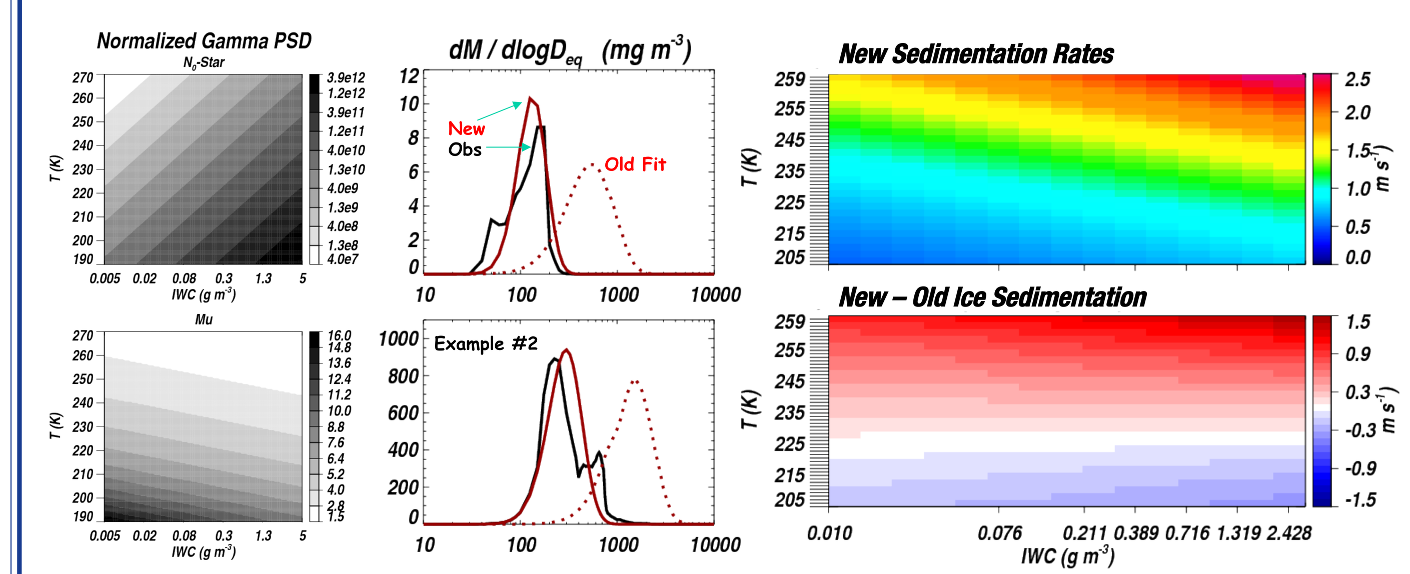
③ Right Column: Sorting by system size yields composite heating modes that are a mix of many states; however, system size is systematically tied to system duration. ***Possible interpretation: Organization (defined according to heating structures!) may be mostly independent of system size, and consistent with the above interpretation, largely independent of duration.***



3a. Recent GCM Parameterization Development

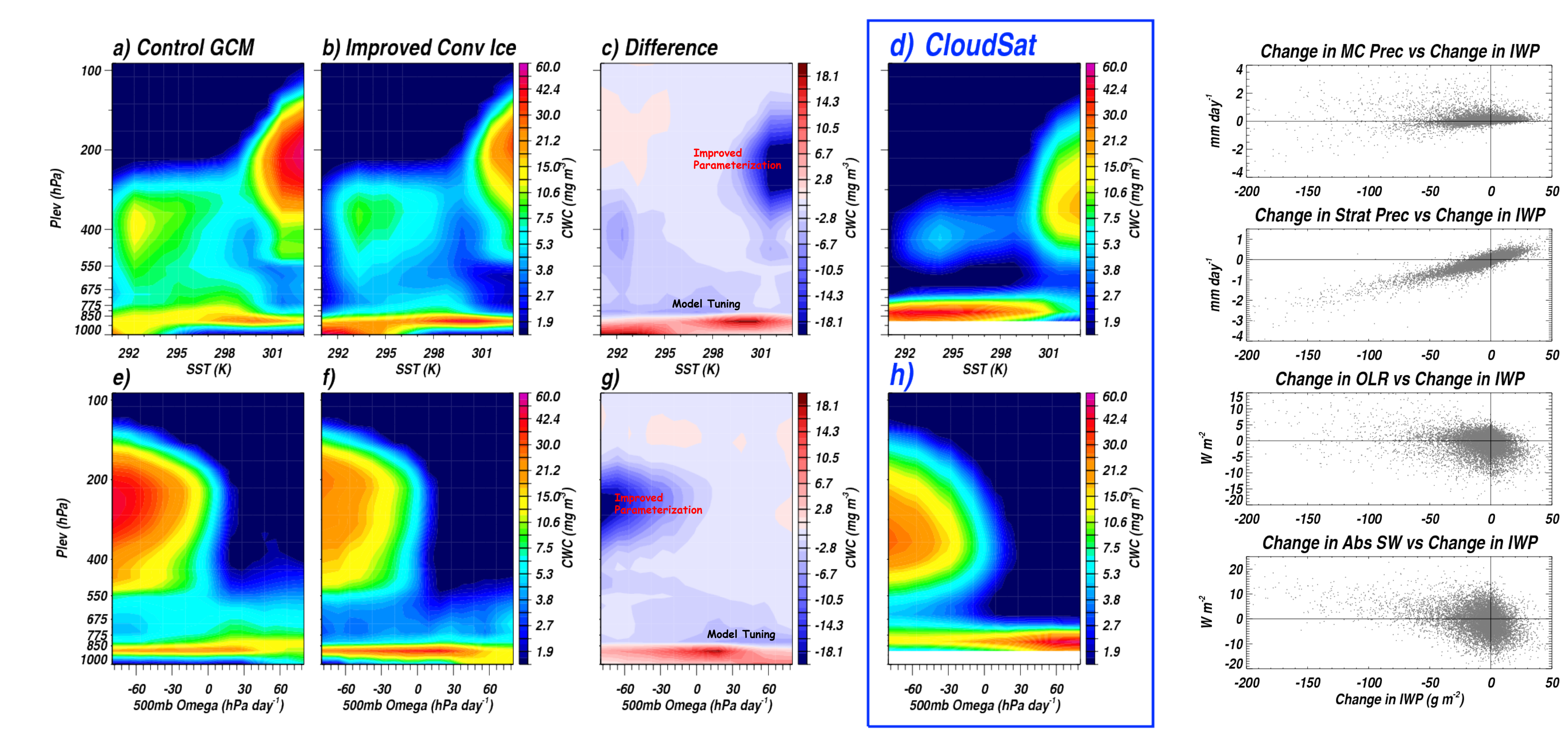
Detrainment of ice in our improved convective ice parameterization is informed by a number of NASA field experiments (Elsaesser et al. 2016, J. Climate, in press). We use data from in-situ flights associated with deep anvil clouds (**e.g. black segments to right**). We assume gamma functions for ice particle size distributions (PSDs), and allow the intercept / shape parameters to vary as a function of temperature (T) and IWC (below).





Our new ice mass distributions agree with observations better than our old fits (left). While particles are smaller, they fall faster when new particle fall speed information is incorporated. Ice particles detrain if their fall speeds are within a small interval of the parameterized convective updraft velocity. This detrained ice can serve to initiate the stratiform anvil cloud.

3b. Impacts on Clouds and Surface Rainfall



Even before we parameterize organized convection, incorporation of the new convective ice parameterization into the GISS GCM leads to model improvement (e.g. a too-high IWC climatology in the CMIP5 GISS GCM is now substantially reduced, with closer agreement between GCM cloud profiles and satellite retrievals noted for a number of environmental states). Stratiform rainfall decreases (global: 1.72 to 1.53 mm day^{-1}), and convective rain slightly increases (on average) as IWP decreases. The percent of stratiform rainfall drops from 45% to 35% over the 20N-20S domain (Schumacher and Houze [2003] estimated an average of 40% using TRMM). OLR and absorbed shortwave radiation (Abs SW) changes are more weakly correlated with changes in IWP. Despite decreases in IWC, the highest-IWC clouds (which is the cloud type that the convective ice parameterization mostly impacts) remain optically thick, and thus, there is some reason to expect a more muted change in radiation fields. However the impacts on radiation require further analysis to be fully understood.

4. Conclusions/Future Work

Our GCM convective ice parameterization will serve as a starting point for simulating stratiform anvil cloud (which is an important component of organized convection). The simulation of organized convection (especially the anvil) requires information on temperature/moisture structures, detrained condensate, PSDs, particle fall speeds and diabatic heating profiles. In addition to using GPM diabatic heating as benchmarks for heating profiles, our future work will entail using environment information (T / qv) from satellite sounders, ice/liquid condensate retrievals from GPM DPR/GMI (and constellation members), vertical wind shear (likely from re-analysis products), and convection/environment characteristics from the GPM Precipitation Feature (PF) database. The overall goal is to have a parameterization that not only makes the right convection in the appropriate environment, but responds in a physically plausible way to a climate change so that the complete deep convective contribution to cloud feedback is understood.